A stochastic approach for multilayer deposition and resuspension in turbulent flows

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Introduction. Particle resuspension corresponds to the detachment of particles from surfaces (for instance, sand resuspension from dunes or colloidal resuspension from deposits as in Henry and Minier (2014b)). The present study aims at presenting the various mechanisms at play in particle resuspension and, through the description of a stochastic approach for particle resuspension, at highlighting how unified multi-scale approaches can be developed.

Monolayer resuspension. First, resuspension from mono-layered systems is described considering the case of colloidal particles, where resuspension occurs mostly through rolling motion. In that case, the stochastic model is based on a three-stage scenario (as depicted in Fig. 1): particles are set into motion when the balance between adhesion forces (between particles and surfaces) and hydrodynamic forces is ruptured; particles then roll on the rough surface; particles can then detach upon rocking on a large-scale asperity if their kinetic energy is higher than the adhesion potential energy.

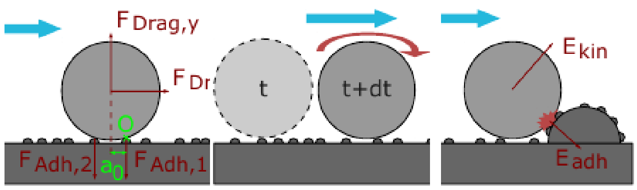

Figure 1: 2D sketch of the three-stage scenario for the monolayer resuspension model. Reprinted from (Henry et al., 2012a). Copyright 2012 with permission from American Chemical Society.

This stochastic model for monolayer resuspension has been compared and validated with various experimental data (Henry et al., 2012a). Fig. 2 shows that the resuspension of colloidal particles from rough surfaces in turbulent flows is well-captured by the approach (Henry and Minier, 2014b).

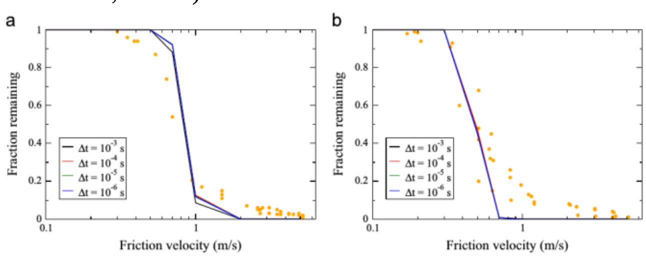

Figure 2: Fraction of particle remaining on the surface after exposure to an airflow with varying friction velocity: numerical (lines) and experimental results for 10 μm (a) and 20 μm (b) alumina. Reprinted from Henry and Minier. (2014b). Copyright 2014 with permission from Elsevier.

Multilayer resuspension. Second, multilayer resuspension is modelled using an extension of the previous model for monolayer resuspension, i.e. a three-stage scenario where: large clusters exposed to the flow can roll on deposited particles and are re-suspended upon hitting other protruding clusters (see Fig. 3). To that extent, we consider the balance between hydrodynamic drag forces and cohesion forces (i.e. particle-particle adhesion forces in the cluster) only.

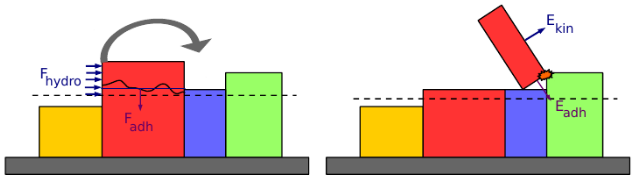

Figure 3: 2D sketch of the scenario retained for the multilayer resuspension model (three-stage scenario).

This new model naturally captures the fact that multilayer resuspension occurs either through single particle resuspension or cluster being detached (or a combination of both) since the balance between cohesion forces and hydrodynamic forces is properly accounted for. The effect of deposit ageing (i.e. consolidation of the cluster) on multilayer resuspension is also analysed by coupling this approach with a model for deposit consolidation.

Conclusion. The present study thus illustrates that a single modelling approach (here in the framework of stochastic Lagrangian approaches) can be developed to model the whole resuspension process provided that the coupling between particle-fluid, particle-surface and particle-particle interactions is properly accounted for.
The present study also highlights the limitations in the current understanding of particle resuspension (especially for multi-layered structures) and brings out suggestions for further experimental/numerical analyses.

Suggested readings

Henry C., Minier J.P. and Lefèvre G. (2012a). Adv. Colloid Interfac., **185-186**, 34-76

Henry, C., Minier, J.-P. and Lefèvre, G. (2012b) Langmuir, **28**, 438-452

Henry, C. and Minier, J.-P. (2014a) J. Aerosol Sci., **77**, 168-192

Henry, C. and Minier, J.-P. (2014b) Prog. Energ. Combu., **45**, 1-53